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THE REMOVAL OF ORGANIC CONTAMINANTS FROM SECONDARY SEWAGE EFFLUENTS USING GRANULAR REGENERABLE ACTIVATED CARBON

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Division of Water Supply and Pollution Control
Advanced Waste Treatment Research Program
Robert A. Taft Sanitary Engineering Center
Cincinnati 26, Ohio

by

Research and Development Department
Pittsburgh Chemical Company
Pittsburgh, Pennsylvania

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INTRODUCTION

Conventional sewage treatment methods do not remove all of the soluble compounds present in the raw sewage. Inorganic materials are not appreciably affected by sewage treatment and even highly treated sewage effluents contain 50 to 150 ppm. of organics. The ultimate objective of this research program is to establish the economic feasibility of removing the organic matter from secondary sewage effluents using granular activated carbon in a column process.

The natural ability of activated carbon to adsorb organic matter from solution is well known and there was little doubt that activated carbon would adsorb the organics from sewage effluent. However it had not been established that a granular carbon used for this purpose in a column process would have an economically practical capacity or that the carbon could be reactivated for reuse. The possibility existed that the more refractory organics exemplified by the sodium salts of the alkyl benzene sulfonates would form inorganic residues during thermal reactivation which would interfere with the adsorptive properties of the carbon in subsequent cycles.

The current study was initiated to obtain an approximation of the optimum bed depth and flow rates necessary for maximum economic utilization of the adsorptive properties of the carbon and to examine the feasibility of regenerating the carbon for reuse by thermal reactivation or an alternative procedure. To eliminate the concentration and composition variables encountered in a real sewage effluent and because ABS was believed to be typical of the refractory organics likely to interfere with the regeneration of the spent carbon, a solution of ABS in water was selected as the effluent for the first phase of the program. In the second phase of the program a column test was made on the effluent from a secondary sewage treatment plant.

SUMMARY

Granular activated carbon in a continuous column process has demonstrated an ability to reduce the ABS content of aqueous solutions to negligible levels. Virgin carbon removed ABS from a 10 ppm. solution to a 0.5 ppm. breakpoint, at a dosage of 0.5 lb./1000 gal., at a flow rate of 2.5 gallons per minute per square foot of cross sectional bed area. Tests at higher flow rates indicate that the carbon dosage is primarily a function of residence time and that a dosage of 0.5 lb./1000 gal. can be obtained at flow rates as high as 10 gpm./ft.^{2} provided that sufficiently deep beds are used.

Treatment of secondary sewage effluent, containing approximately 50 ppm. COD and 5 ppm. ABS, with granular activated carbon in a countercurrent column process produced effluents having COD values of from 12 to 20 ppm. and ABS levels well under 0.5 ppm. It is estimated that for this treatment the amount of carbon regenerated would be less than 1 lb./1000 gal. of effluent. No attempts were made to determine the nature of the unadsorbed COD constituents. Consequently it has not been precluded that part of this residual could be due to oxidizable inorganics or to colloidal dispersions of non degradable sewage constituents and/or carbon. If the unadsorbed COD is due to organic matter in solution there is a possibility that increased residence time would effect more complete removal.

SUMMARY (continued)

If it is assumed that the COD level can be reduced to 5 ppm. by increasing the column residence time and that the average adsorption capacity of the carbon will be 50% of its virgin capacity, overall treatment costs to accomplish this degree of purification are conservatively estimated to be in the range of $0.06 - $0.08/1000 gallons of secondary effluent.

Analysis of granular activated carbon before and after its saturation by the adsorption of ABS from a tap water solution showed that the adsorbed ABS was present predominately as the calcium salt. In accelerated batch reactivation tests granular carbon was alternately loaded with Ca-ABS and thermally reactivated for ten complete cycles. At the completion of the test the ash content of the carbon had doubled, the added ash being insoluble in water but soluble in acid. Further, after ten cycles the capacity of the carbon for the adsorption of ABS from a dilute solution was approximately half of the virgin capacity. Preliminary tests indicate that if it is necessary to prevent this ash build-up in practice, it can probably be done by treatment of the carbon after thermal reactivation with acid or preferably a less corrosive reagent for the solution of calcium salts. Elimination of the insoluble ash build-up by the conversion of the adsorbed Ca-ABS to the free acid or sodium salt prior to thermal reactivation is not considered feasible since it appears impractical to obtain more than a 60% conversion.

Thermal reactivation of granular carbon, once used for the treatment of secondary sewage effluent, restored its virgin adsorptive properties despite a 6-9% increase in the total ash content. The alkyl benzene sulfonates represent only a fraction of the total organics present in secondary sewage effluent and therefore only a fraction of the total organics present on the spent carbon. As a consequence the build-up of insoluble ash should in practice be markedly less than that obtained in the accelerated test where ABS was the only adsorbate. For this reason it is concluded that cyclic reactivation tests in which the carbon is exhausted by contact with real sewage effluent are required before the consideration of pre or post reactivation treatments is necessary.

RECOMMENDATIONS

The following recommendations are made for future work on this program:

(1) That additional laboratory studies be conducted to obtain preliminary information on the unadsorbed fraction of the COD as well as to determine the feasibility of adsorbing the COD residual on activated carbon.

(2) In the event that the COD residual is due completely or in part to dissolved organic matter, that column studies on a real sewage effluent be conducted at higher residence times than those used in the initial tests in order to determine the effects of this variable on COD removal.

(3) That cyclic regeneration tests be performed in which granular carbon is alternately exhausted with real sewage effluent and thermally reactivated in order to determine the extent of insoluble ash build-up and its effects on the operating capacity of the carbon.

RECOMMENDATIONS (continued)

(4) That column tests be conducted to more accurately define the rate at which the inlet end of the carbon bed becomes saturated with the organic matter in secondary sewage effluent. This data is necessary in order to design adsorbers that will ensure maximum utilization of the adsorptive capacity of the carbon.

(5) That the effects of suspended solids on the adsorptive capacity of the carbon and on the pressure drop in column operation be examined in order to determine whether pre-filtration of the secondary effluent is necessary.

(6) That engineering studies directed towards the selection of the most economically practical types of adsorber for this operation and the design of a pilot plant be initiated. The pilot plant design should be sufficiently flexible to permit the evaluation of the types of adsorber that are not ruled out economically. It is further recommended that the engineering study be initiated as soon as possible in order that current bench scale studies can be utilized to obtain the data necessary for the optimum design.

EXPERIMENTAL

MATERIALS

Activated Carbons:-

Three samples of Pittsburgh granular carbon, selected to cover the range of adsorptive capacities in commercial liquid phase carbons, were used in this investigation.

Alkyl Benzene Sulfonate:-

A sample of standard ABS obtained from the Association of American Soap and Glycerine Producers Incorporated was used for all of the tests.

ISOTHERM TESTS

Apparatus:-

Spex Mixer Mill, equipped with steel vial and steel balls.
Burrell "Wrist-Action" Shaker.
Erlenmeyer Flasks, stoppered, 500 and 1500 ml.
Buchner funnels and filter flasks.
Whatman No. 3 filter paper.
Analytical and semi micro balances.

Procedure:-

The granular carbons selected for testing were pulverized to a 95% - 325 mesh size in the Spex mill. Various weights of the pulverized carbon, between 10 and 200 mg. were added to either 500 or 1500 ml. volumes of ABS solution in Erlenmeyer flasks. The stoppered flasks were mounted on the shaker and agitated for two hours. At the end of this time the contents of the flasks were filtered and the ABS content of the filtrate determined. A preliminary rate test in which 100 mg. of pulverized carbon was agitated with a 50 ppm. solution of ABS for 0.5, 1, 2, and 4 hours showed that the amount of ABS adsorbed after two hours was equal, within the limits of experimental error, to that adsorbed after four hours. The ABS solutions used had initial concentrations ranging from 1.3 to 54.9 ppm.

For each isotherm, "blank" determinations were made in which ABS solution without carbon was subjected to the same filtration procedure as the samples containing carbon. The net weight of ABS adsorbed (x) for each sample was determined by subtracting the filtrate concentration from the appropriate "blank" filtrate concentration. This value was divided by the weight of carbon used in the test to determine the weight adsorbed per gram of carbon (x/m). The amount adsorbed (x/m) was plotted as ordinate and residual filtrate concentration (c) as abscissa on log-log graph paper and the best straight line was drawn through the points.

COLUMN TESTS ON ABS SOLUTION

Apparatus:-

The columns consisted of one inch diameter pyrex pipe sections. Pyrex pipe reducers 1" x 3/8" were flanged to the top and bottom of each section. A piece of 50 mesh stainless steel screen was held by gaskets in the lower flange of each section to support the carbon bed. Connections between the columns and from the pumps to the columns were made with polyethylene tubing which was attached to the pyrex pipe tubing which was attached to the pyrex pipe connections by Sentinel "quick-disconnect" couplings.

The 10 ppm. ABS solution used for these tests was prepared in a 200 gallon tank and was fed to the columns by means of Zenith laboratory, metering, gear pumps.

Three flow rates were investigated, 2.5, 5.0, and 10.0 gallons per minute per square foot of cross sectional bed area. The bed depth used depended upon the flow rate. Either 3 ft. columns containing 170 g. of carbon to give a 2.5 ft. bed depth or 6 ft. columns containing 340 g. of carbon to give a 5.0 ft. bed depth were connected in series for down flow operation. The bed depths used at each flow rate are listed in Table II (Page 17). Sampling ports were installed after each column section.

A drawing of the apparatus, showing the column arrangement used at 5.0 gpm./ft.^{2} is shown in Figure 1.

Procedure:-

Sufficient carbon to fill one column section was degassed by boiling in water for a ten minute period. The slurry was spooned into the column, which was partially filled with water, at a rate such that the carbon level never rose above the water level.

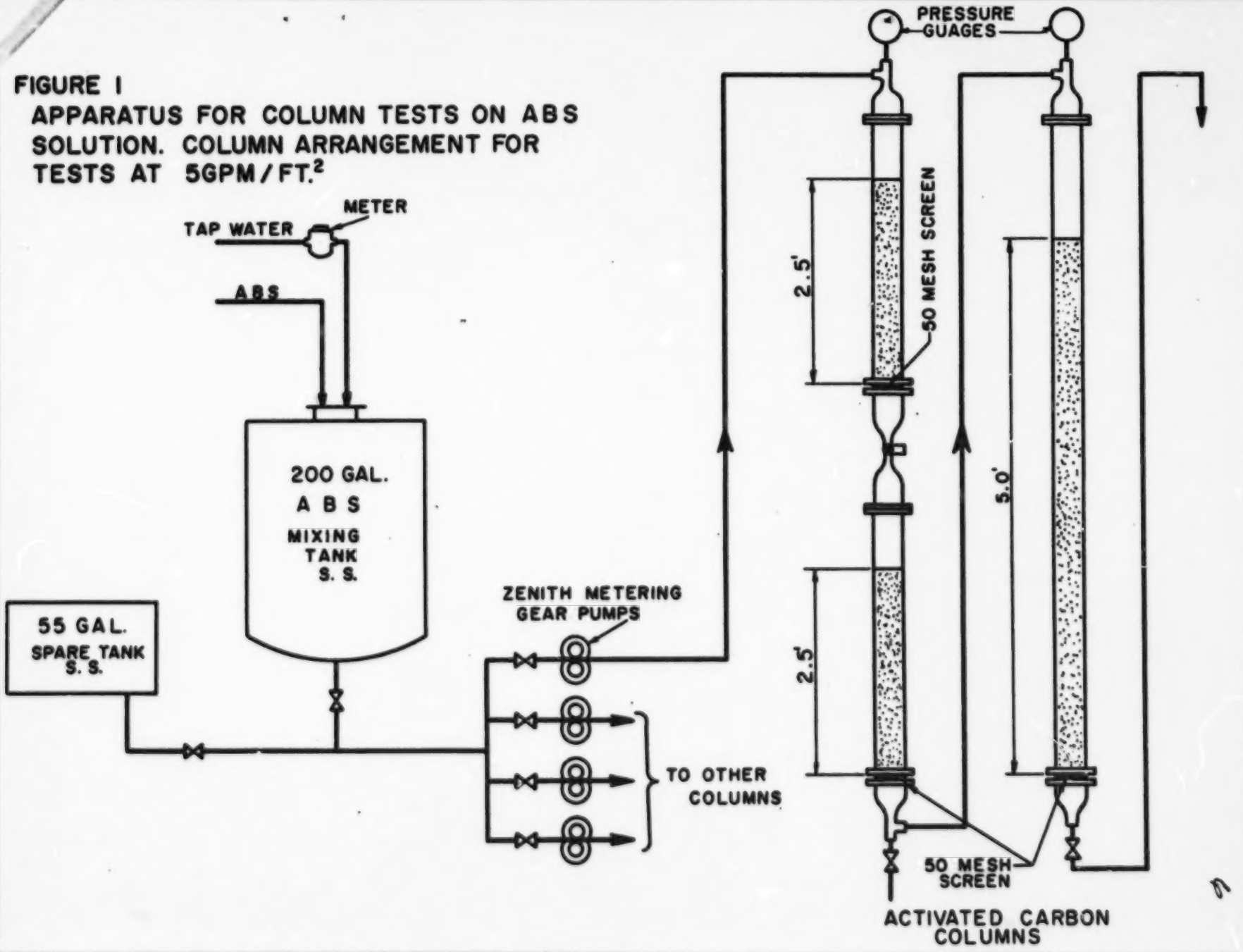
A 10 ppm. solution of ABS in tap water was prepared in the mixing tank. This solution was pumped to the columns at the desired rates by means of the metering pumps. Break through curves were established at each flow rate by collecting samples from each column section at intervals and determining the ABS content. The ABS content of each batch of influent prepared was also determined.

COLUMN TESTS ON SECONDARY SEWAGE EFFLUENT

Pleasant Hills Sewage Treatment Plant:-

The Pleasant Hills Sewage Treatment Plant in suburban Pittsburgh was selected as the site for the column tests. This is a well designed and efficiently operated plant which has been in operation since 1959 and which employs activated sludge secondary treatment. An area having a population of 17,000 is serviced. The influent is almost completely domestic sewage; the only exceptions being the wastes from several laundromats in the area.

FIGURE 1
APPARATUS FOR COLUMN TESTS ON ABS SOLUTION. COLUMN ARRANGEMENT FOR TESTS AT 5GPM/FT.^{2}



Pleasant Hills Sewage Treatment Plant:- (continued)

The plant is designed for an average flow capacity of 3.0 mgd. and a maximum flow of 4.5 mgd. Normally the average flow is approximately half of the design figure. However, during the test period, which extended from mid-February to mid-April, considerable wet weather was experienced and the average flow during this time was 2.8 mgd. During this period the 5 day BOD values averaged 147 ppm. in the influent and 7 ppm. in the final effluent corresponding to an average reduction of 95%. Suspended solids averaged 148 ppm. in the raw sewage and 20 ppm. in the final effluent for an average overall reduction of 87%.

A flow sheet and a brief description of the operation of the Pleasant Hills Plant is given in the Appendix (Page 34).

Apparatus:-

A photograph of the apparatus is shown in Figure 2.

Final effluent, before chlorination, was withdrawn continuously from the main line supplying the spray water to the aeration tanks through a 3/4 inch pipe installed between that line and the reservoir feeding the column system. The final effluent was passed through a 3 ft. deep graded sand filter, housed in a four inch diameter pyrex pipe, into a 55 gal. drum, fitted with an overflow pipe. The sand filter was piped so that it could be back washed at intervals with final effluent.

Filtered effluent was pumped from the 55 gal. drum at a flow rate of 10 gpm./ft.^{2} by means of a Zenith laboratory metering gear pump. Connections from the reservoir to the pumps, from the pump to the first column and between the columns were made with copper tubing.

Each column consisted of a 6 ft. section of 2 in. i.d. pyrex pipe. Pyrex pipe reducers, 2 in. x 3/8 in. were flanged to the top and bottom of each pipe section. A 50 mesh stainless steel screen was inserted in the bottom flange to support the carbon bed. Four such sections were connected in series for down flow operation. A pressure gauge was mounted at the top and a sampling port was installed at the bottom of each column section. Each column contained 1360 g. of granular carbon which provided a bed depth of 5 ft. per section and an overall bed depth of 20 ft.

Procedure:-

Granular carbon was charged to the columns by the procedure outlined above for the column tests on ABS solution. Filtered effluent was pumped to the columns at a flow rate of 10 gpm./ft.^{2}. Effluent samples were collected from each column section at intervals and analyzed for ABS and COD. Simultaneously samples were collected from the reservoir for the same analyses. Initially volatile solids determinations were made but this practice was discontinued because of the very erratic results obtained.

At the start of the test program grab samples of the column influent and effluent were collected. Later the sampling procedure was modified and 24 hr. composite samples were collected.

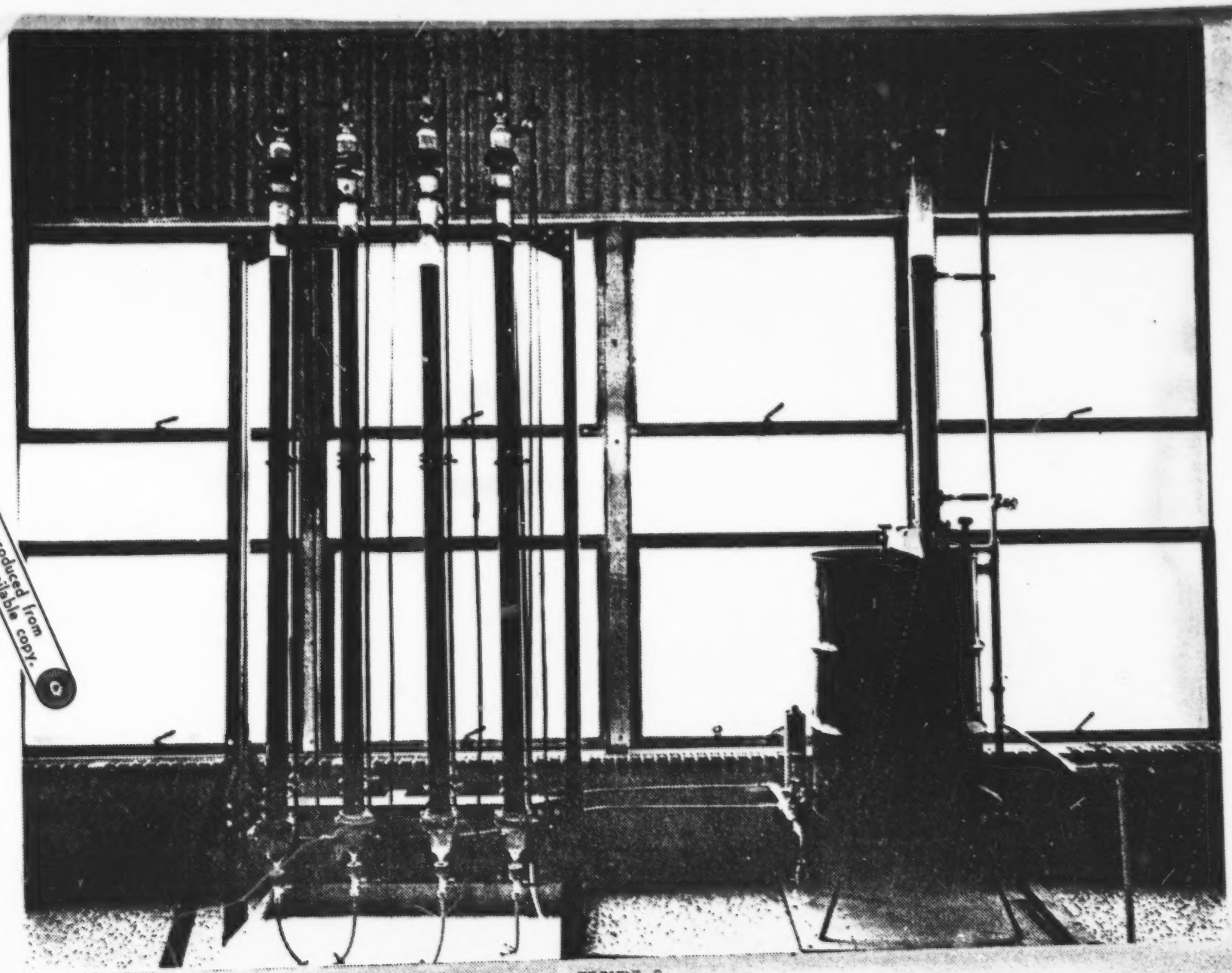


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FIGURE 2

APPARATUS FOR COLUMN TESTS ON SECONDARY SEWAGE EFFLUENT

Procedure:- (continued)

The test was continued until the effluent from the fourth column showed an ABS content of 0.5 ppm. At this point the system was shut down. The carbon in the first column was removed and thermally reactivated by the procedure outlined below. The reactivated carbon was recharged to the empty column and this column was installed in the number four or final position in the series.

When the ABS content of the effluent from the fourth column again reached 0.5 ppm., the carbon in the original number two column, which had occupied the first position in the second cycle was reactivated, recharged and returned to service in the number four position. The test was terminated when the third cycle was completed, that is, when a 0.5 ppm. ABS breakthrough was obtained from the fourth column.

REACTIVATION TESTS

Batch Cyclic Reactivation Tests:-

A 500 g. sample of granular carbon was immersed in 4.5 gal. of a 7000 ppm. solution of Na-ABS in a 5 gal. bottle. The bottle was agitated intermittently for a six hour period. After the liquid was decanted from the bottle the carbon was washed out, filtered, and rinsed thoroughly with water. The carbon was then immersed in 4.5 gal. of 3400 ppm. calcium chloride in a second 5 gal. bottle which was also agitated intermittently for a six hour period. The calcium chloride solution was then decanted from the bottle and the carbon was washed out, filtered and rinsed thoroughly with water.

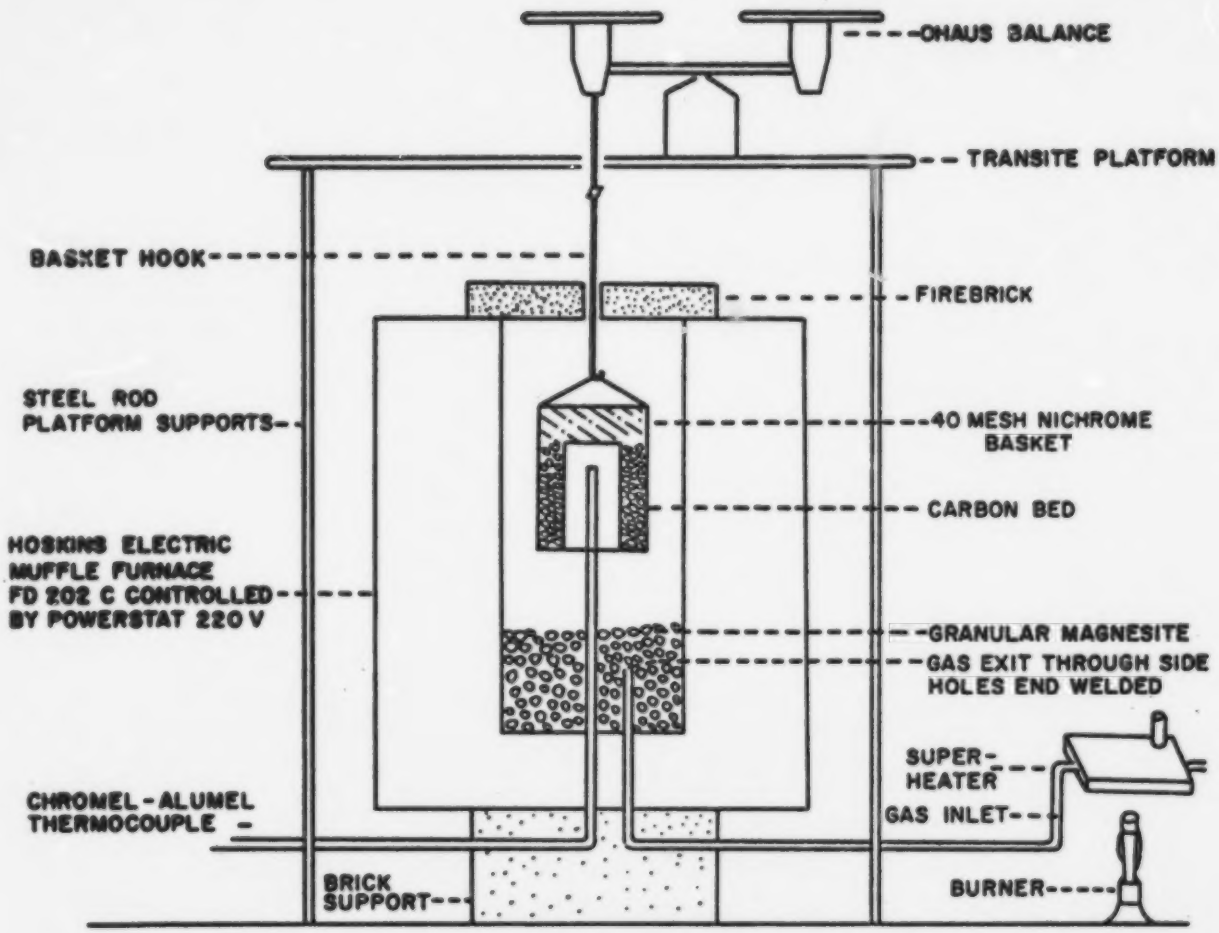
The dried spent carbon was thermally reactivated in 100 gram batches in the laboratory weighing furnace (Figure 3). The furnace was preheated to 1700°F and 100 g. of carbon was transferred to the nichrome basket. The basket was placed in the hot zone of the furnace and suspended from the balance arm. An atmosphere of natural gas, air and steam was passed through the furnace. The reactivation was continued until the original apparent density was restored.

This procedure of alternate saturation with Ca-ABS and thermal reactivation was repeated for a total of ten complete cycles. The molasses and iodine activity of the reactivated carbon was determined at intervals. In later cycles the reactivation time was increased to obtain apparent densities lower than those of the virgin carbon in an attempt to maintain the activity of the carbon at a satisfactory level.

Reactivation of Spent Carbon from Sewage Plant Tests:-

Spent carbon from the sewage plant tests was reactivated in a pilot plant rotary furnace[1] which has a capacity of approximately one gallon of

(1) American Gas Furnace Company Rotary Gas Carburizer, Type No. 1-F, modified in our pilot plant.



LABORATORY WEIGHING ACTIVATOR

FIGURE 3

Reactivation of Spent Carbon from Sewage Plant Tests:- (continued)

carbon. A temperature of 1700°F and an atmosphere consisting of 34%-vol. steam and 66%-vol. air was used. Under these conditions the carbon was restored to essentially virgin activity at a retention time of 14 minutes. Standard activity tests were made before and after reactivation.

Reactivation Tests with Steam at Lower Temperatures:-

A sample of spent carbon from the column tests on ABS solution was refluxed with twice its volume of 5% hydrochloric acid, thoroughly rinsed with water and dried.

A one hundred gram aliquot of the dried sample was transferred to a nichrome basket and placed in a muffle furnace preheated to 950°F. Steam was passed through the furnace at rate of 3 g./min. At intervals the basket was removed from the furnace and weighed. The reactivation was continued until an apparent constant weight was obtained.

This procedure was repeated using a second 100 g. aliquot of the acid treated carbon and a furnace temperature of 650°F. Standard activity values were obtained on the carbon before and after reactivation.

Conversion of Adsorbed ABS to Free Acid or Sodium Salt:-

1. The spent carbon from the first column section used for the treatment of a 10 ppm. solution of ABS at 2.5 gpm./ft.^{2} was thoroughly rinsed and oven dried. The calcium, magnesium and sodium contents of the carbon were determined.

2. A 60 gram aliquot of the spent carbon was charged in water to a percolation column, 1.25 in. i.d., 10 in. in length, fitted with a 5 mm. i.d. bottom outlet, fabricated of pyrex tubing. This quantity of carbon was sufficient to give a bed depth between 6 and 7 in. The carbon bed was supported by a glass wool plug.

3. One liter of 5% hydrochloric acid was percolated through the bed at a flow rate of 26 ml./min. This flow rate corresponded to the same contact time that would be obtained at 5 gpm./ft.^{2} in a 3 ft. bed. The effluent was collected in 100 ml. fractions and the calcium and magnesium content of each fraction was determined.

4. After one liter of effluent was collected, one liter of tap water was passed through the bed at the same flow rate. The effluent was collected in 100 ml. fractions and the calcium and magnesium contents determined.

5. Steps 2 and 3 were repeated using a 5% sodium chloride solution instead of the 5% HCl solution.

CORROSION TEST

A test coupon (7.69 cm. X 2.93 cm. X 0.073 cm.) was cut from a sheet of mild steel. The coupon was sand blasted, washed in turn with dilute hydrochloric acid, water and acetone, dried and accurately weighed. The strip was imbedded in the fourth carbon column at the sewage treatment plant and left there for 31 days. At the end of this period the coupon was removed, soaked in boiling ammoniacal ammonium citrate solution, washed in turn with water and acetone, dried and reweighed.

ANALYTICAL METHODS

Effluent Analyses:-

ABS	Methylene Blue Method[1]
COD	Dichromate Method[2] (all COD values given are chloride corrected)
Chlorides	Potentiometric Method[3]
Volatile Solids	Total Volatile and Fixed Residue[4]
Calcium	EDTA titration
Magnesium	EDTA titration

Carbon Analyses:-

Apparent Density	PCC Method[5]
Ash	PCC Method[6]
Iodine Number	PCC Method[7]
Molasses Number	PCC Method[8]
Calcium	EDTA titration after ashing and fusion
Magnesium	EDTA titration after ashing and fusion
Sodium	Flame photometrically

1. "Standard Methods for the Examination of Water and Wastewater", Eleventh Edition, pp. 245 - 248.
2. Ibid, pp. 390 - 402.
3. Ibid, pp. 279 - 282.
4. Ibid, p. 327.
5. "Test Methods of the Carbon Plant Control Laboratory", Pittsburgh Chemical Company, 1960, Test No. 4.
6. Ibid, Test No. 7.
7. Ibid, Test No. 14.
8. Ibid, Test No. 15.

RESULTS AND DISCUSSION

ISOTHERM TESTS

A typical isotherm plot is shown in Figure 4. The isotherm has been extrapolated to intersect a vertical line originating at C_o, the initial concentration. The point of intersection $(x/m)_{C_o}$ should represent the capacity of the carbon for ABS when that carbon is in equilibrium with a solution of concentration C_o. This equilibrium should be attained in at least the first section of a granular carbon bed through which a solution of C_o concentration is being percolated. Theoretical adsorptive capacities obtained in this manner are summarized in Table I for the various ABS concentrations and the three carbons tested.

Carbon A and Carbon B are both high capacity liquid phase carbons. They have essentially the same surface area but differ in that Carbon A has a larger fraction of its surface area in pores in the 20 to 50 Å range. It is apparent that at both the 54.9 and 11.6 ppm. initial ABS concentrations the two carbons have essentially the same capacity for ABS. Carbon C has a lower surface area than A or B and an obviously lower ABS capacity. It was concluded that the surface area of the carbon was the prime consideration for ABS adsorption and Carbon B was used for all of the column tests. Preliminary tests indicate that efficient ABS adsorption could be effected at comparatively high flow rates, for this reason a relatively high mesh size carbon, 8 x 30, was chosen for the column tests to minimize pressure drop.

COLUMN TESTS ON ABS SOLUTION

Breakthrough curves at the three flow rates investigated are shown in Figure 5.

The effects of increasing bed depth are apparent from the first set of curves at the 2.5 gpm./ft.^{2} flow rate, where three 2.5 ft. beds were connected in series. In order to compare the performance of the columns a breakpoint of 0.5 ppm. ABS was selected. At 2.5 gpm./ft.^{2} less than 400 gallons were collected from the first 2.5 ft. section before the breakpoint was reached whereas approximately 1200 gallons and 2200 gallons were collected from the second and third sections respectively. The same general trend of a marked increase in volume of acceptable effluent with increasing bed depth can be observed in the breakthrough curves at the other flow rates shown in Figure 5. If, at any flow rate, the total bed depth had been increased by the addition of 2.5 or 5.0 ft. bed sections, a point would be reached where the volume of acceptable effluent would increase linearly with bed depth. However, in the case of a dilute solution such as this, a prohibitively long time would be required to establish that point.

The data calculated from the breakthrough curves have been summarized in Table II. At each flow rate and bed depth the throughput volume to a 0.5 ppm. breakpoint is listed. The weight of ABS adsorbed per unit weight of carbon was determined by graphical integration of the breakthrough curves. From the throughput volume and the weight of carbon in each column the carbon dosage in terms of lb./1000 gallon of 10 ppm. solution was calculated. The total ABS adsorbed at each bed depth was also obtained by graphical integration of the breakthrough curves, and represents in each case the amount of ABS adsorbed by the first section, by

FIGURE 4
A B S ADSORPTION ISOTHERM
CARBON SAMPLE B

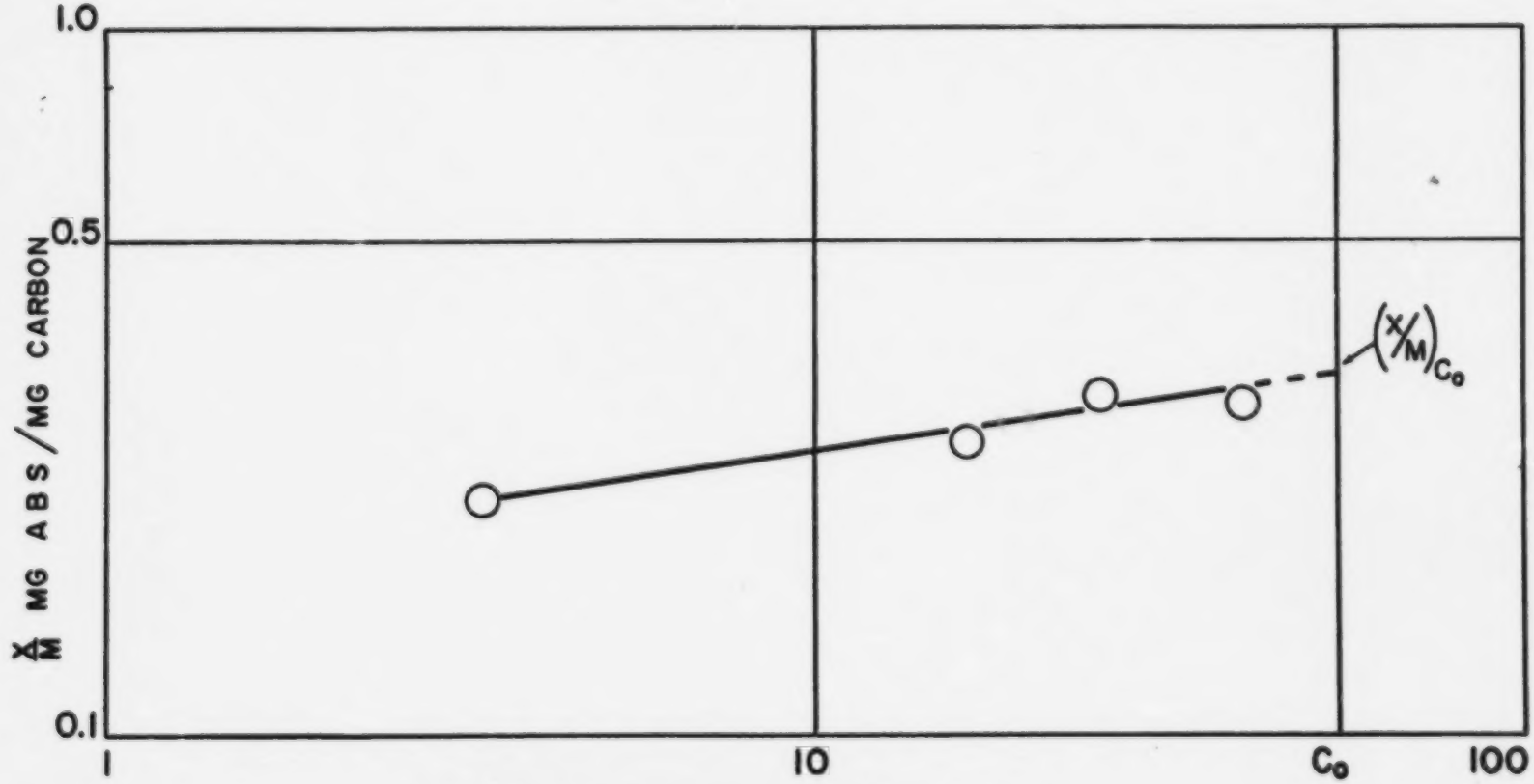


TABLE I

ADSORPTION CAPACITIES ($\frac{X}{M}$)Co) OF ACTIVATED CARBONS FOR ABS

CARBON SAMPLE	INITIAL ABS CONCENTRATION PPM.	$\frac{X}{M}$Co g.ABS/100 g.C.
A	54.9	28
B	54.9	32
C	54.9	18
A	11.6	22
B	11.6	21
B	2.0	15
B	1.3	13

FIGURE 5
BREAKTHROUGH CURVES FOR THE REMOVAL
OF ABS FROM A 10 PPM AQUEOUS SOLUTION

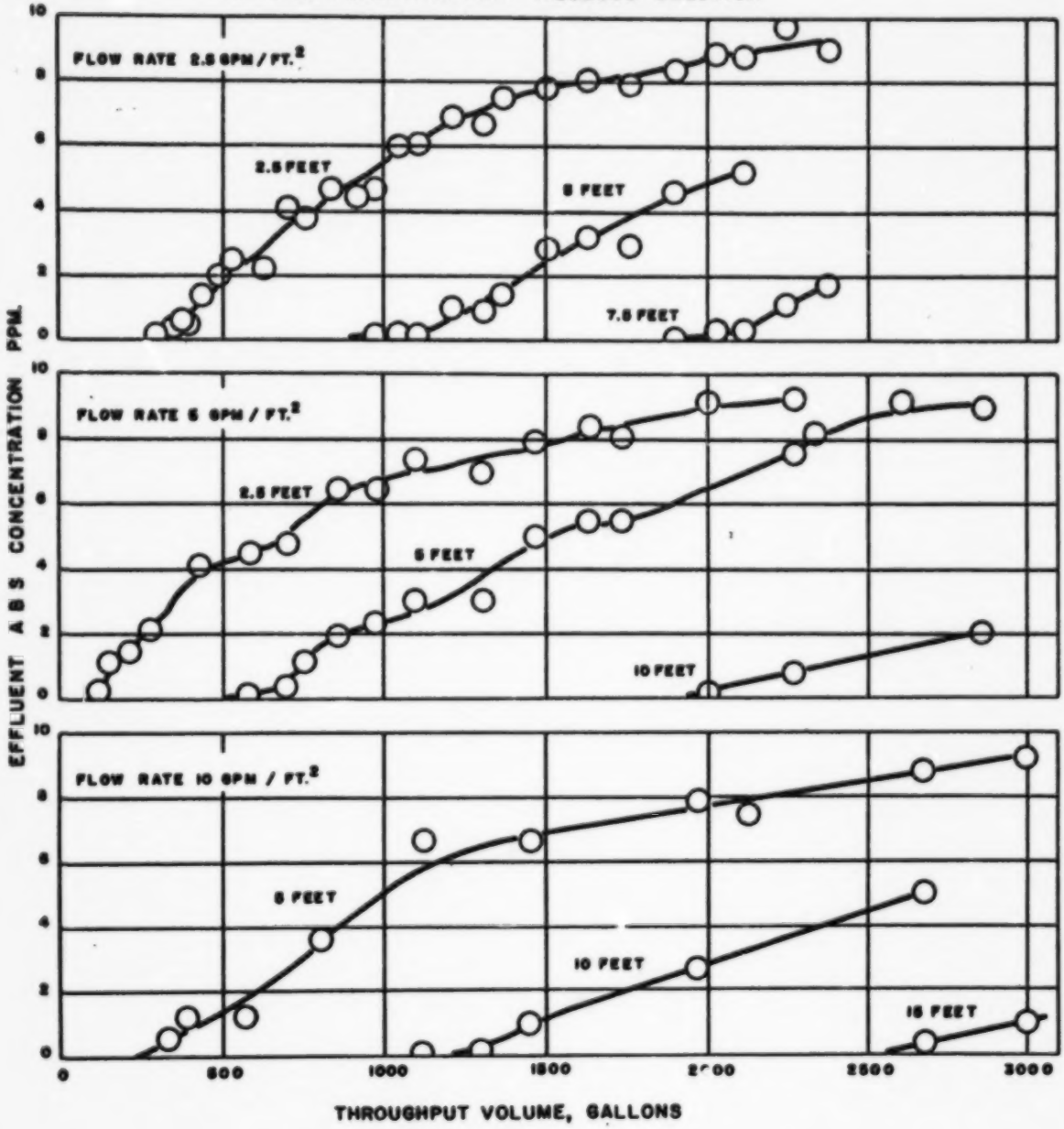


TABLE II

COLUMN CAPACITY DATA FOR THE ADSORPTION OF ABS FROM A 10 ppm. AQUEOUS SOLUTION

FLOW RATE gpm./ft.^{2}	BED DEPTH FEET	CAPACITY TO 0.5 ppm. BREAKPOINT		TOTAL ABS ADSORBED[1] g./100g.C.	CARBON DOSAGE lb./1000 Gal.
		THROUGHPUT VOL. GAL.	ABS ADSORBED g./100g.C.		
2.5	2.5	363	8.9	24.0	0.97
	5.0	1216	14.3	20.5	0.62
	7.5	2148	15.9	15.9	0.53
5.0	2.5	141	3.1	19.7	2.66
	5.0	730	8.1	17.7	1.03
	10.0	2190	12.7	12.7	0.69
10.0	5.0	332	3.7	14.3	2.22
	10.0	1380	7.7	12.8	1.09
	15.0	2760	10.4	10.4	0.82

1. To 0.5 ppm. breakpoint from third column section.

COLUMN TESTS ON ABS SOLUTION (continued)

the first and second sections combined, and by the three sections combined when the effluent concentration from the third section reaches 0.5 ppm.

It is evident from the data in Table II that at 2.5 gpm./ft.^{2} in a 2.5 ft. bed, 5.0 gpm./ft.^{2} in a 5.0 ft. bed and 10 gpm./ft.^{2} in a 10 ft. bed the carbon dosage is approximately 1 lb./1000 gal. The contact time in each case is the same. It seems reasonable to conclude that at 5.0 gpm./ft.^{2} in a 15 ft. bed and at 10 gpm./ft.^{2} in a 30 ft. bed, the contact time and therefore the carbon dosage will be the same as that obtained at 2.5 gpm./ft.^{2} in a 7.5 ft. bed, that is, 0.5 lb./1000 gal.

It is interesting to note that after breakthrough from any column section occurs the carbon in that section still has considerable capacity for ABS adsorption. This is particularly evident from the total ABS adsorbed figures in Table II. At 2.5 gpm./ft.^{2}, for example, the first 2.5 ft. of bed adsorbed 24%-wt. ABS and the first 5.0 ft. of bed adsorbed 20.5%-wt. ABS when breakthrough occurred from a 7.5 ft. bed depth.

This observation suggests that maximum utilization of adsorptive capacity of the carbon can be effected by operating a series of short beds in a countercurrent manner. For example, at 2.5 gpm./ft.^{2} the first 2.5 ft. bed could be removed from service when the effluent from the third section reached the breakpoint and replaced with a fresh bed in the number 3 position.

Carrying out this procedure indefinitely would ensure that only highly saturated carbon would be reactivated. At the higher flow rates a series of deeper bed sections would be necessary.

The maximum capacities obtained in the column tests, from 20 - 24%-wt. ABS are in reasonable agreement with the 22%-wt. figure obtained in the isotherm tests for an initial ABS concentration of approximately 10 ppm.

COLUMN TESTS ON SECONDARY SEWAGE EFFLUENT

The analytical data accumulated during the plant tests are listed in Table III. ABS and COD breakthrough curves for the fourth column, that is for a total bed depth of 20 ft. are plotted in Figure 6. Curves for the intermediate bed depths have been omitted to simplify the diagram. The open points connected by dashed lines represent grab samples. The solid points connected by solid lines represent 24 hour composite samples. Throughput volumes, averages of the influent and effluent analyses and carbon dosages for the three cycles are summarized in Table IV. Included in Table IV are averages of the total flow and the sewage plant analytical data for the corresponding period.

It is immediately apparent from Figure 6 and Table IV that the material contributing to the COD was not completely removed by the activated carbon. A residual of from 12 to 20 ppm. remained in the effluent. No attempt was made to determine the nature of this residual COD.

TABLE III

ANALYTICAL DATA COLUMN TESTS ON SECONDARY SEWAGE EFFLUENT

DATE	TIME	THROUGHPUT (gallons)	ABS ppm. INFLUENT	ABS ppm. Column No. 1	2	3	4	COD ppm. (chloride corrected) INFLUENT	COD ppm. Column No. 1	2	3	4	VOLATILE SOLIDS ppm. INFLUENT	VOLATILE SOLIDS ppm. Column No. 1	2	3	4
2-13	700	254	8.6	1.7	0.3	0.3	0.2	115.7	81.9	63.7	59.7	56.8	130	125	69	73	106
2-14	900	581	7.3	3.0	0.6	0.2	0.1	82.2	57.6	44.7	38.9	41.5	152	73	85	73	76
2-15	715	863	6.0	3.0	0.6	0.1	0.1	90.6	92.0	60.2	35.6	26.8	130	97	121	88	110
2-16	715	1166	6.2	3.5	1.0	0.2	0.1	65.8	42.8	34.0	31.4	17.7	122	91	68	73	83
2-19	850	2038	5.7	3.5	1.1	0.2	0.1	49.2	36.1	23.7	16.1	20.3	118	89	87	95	84
2-21	800	2550	5.3	3.0	1.4	0.3	0.1	62.0	37.3	29.2	24.1	22.1	97	93	84	57	58
2-23	700	3132	4.9	3.7	2.2	1.0	0.3	61.2	56.5	31.2	27.6	25.1	138	106	110	110	107
2-26	645	3904	4.0	2.9	1.6	0.7	0.2	54.7	33.2	28.7	16.9	9.2	119	95	93	87	77
2-28	730	4430	2.8	1.9	1.2	0.6	0.2	43.6	42.9	20.8	24.6	22.2	80	57	71	66	72
3-2	700	5008	4.5	2.9	2.0	1.0	0.4	109.1	42.9	28.1	22.7	18.9	145	82	87	57	78
3-5	700	5880	4.9	3.7	2.8	1.6	0.6	51.5	34.5	26.3	16.1	13.5	110	105	98	88	94
3-9	700	6220	5.2	2.8	1.6	0.5	0	70.7	47.0	26.4	16.2	9.0	56	54	56	48	36
3-12	700	6893	3.6	2.2	1.6	0.8	0.1	36.5	13.4	16.3	8.2	12.2	96	83	74	76	75
3-14	700	7470	3.0	1.8	1.2	0.5	0.1	89.6	41.1	23.6	10.0	3.2	129	106	91	92	93
3-16	730	8041	3.7	2.7	2.1	1.0	0.2	52.0	40.8	27.6	25.5	17.2					
3-18	700	8650	5.5				0.3	36.0				13.3					
3-19	700	8928	7.1	4.1	2.9	1.8	0.5	42.7	28.9	24.2	18.7						
3-20	700	9243	5.7				0.6	54				18.0					
3-21	700	9517		4.6	2.5	1.4			58.5	39.1	35.8						
3-23	1330	9517	3.7					24.8									
3-24	700	9757	4.2					18.3									
3-25	700	10053	4.3				0.1	58.3				21.2					
3-26	700	10364	4.6	3.3	2.3	0.9			34.3	20.3	14.2						
3-27	700	10638	6.0				0.2	63.7									
3-28	700	10924	6.1	4.2	2.3	0.5		44.3	42.2	24.1	15.2						
3-29	700	11183	5.3				0.1	41.7				9.7					
3-30	700	11442	6.1	4.9	3.2	1.1		40.4	28.9	16.3	21.9						
3-31	700	11686	4.7					33.7									
4-1	700	11926	3.4					39.0				9.7					
4-2	700	12287	3.4	2.1	1.6	0.8			16.4	30.3	9.8						
4-3	700	12526	4.5				0.2	34.1				3.0					
4-4	700	12850	4.4	3.4	2.6	1.3	0.3	23.9	40.4	17.3	41.5	0.8					
4-5	700	13117	4.7				0.2	33.3				23.7					
4-6	700	13398	5.0	3.9	3.0	1.5	0.4	36.9	25.5	21.9	15.5	13.1					
4-7	700	13666	3.9				0.5	22.6				15.2					
4-8	700	13926	3.4				0.4	23.0				25.7					
4-9	700	14100		1.7	1.1	0.6	0.3	25.1	20.7	20.0	14.3	18.7					

FIGURE 6 BREAKTHROUGH CURVES COLUMN TESTS ON SECONDARY SEWAGE EFFLUENT

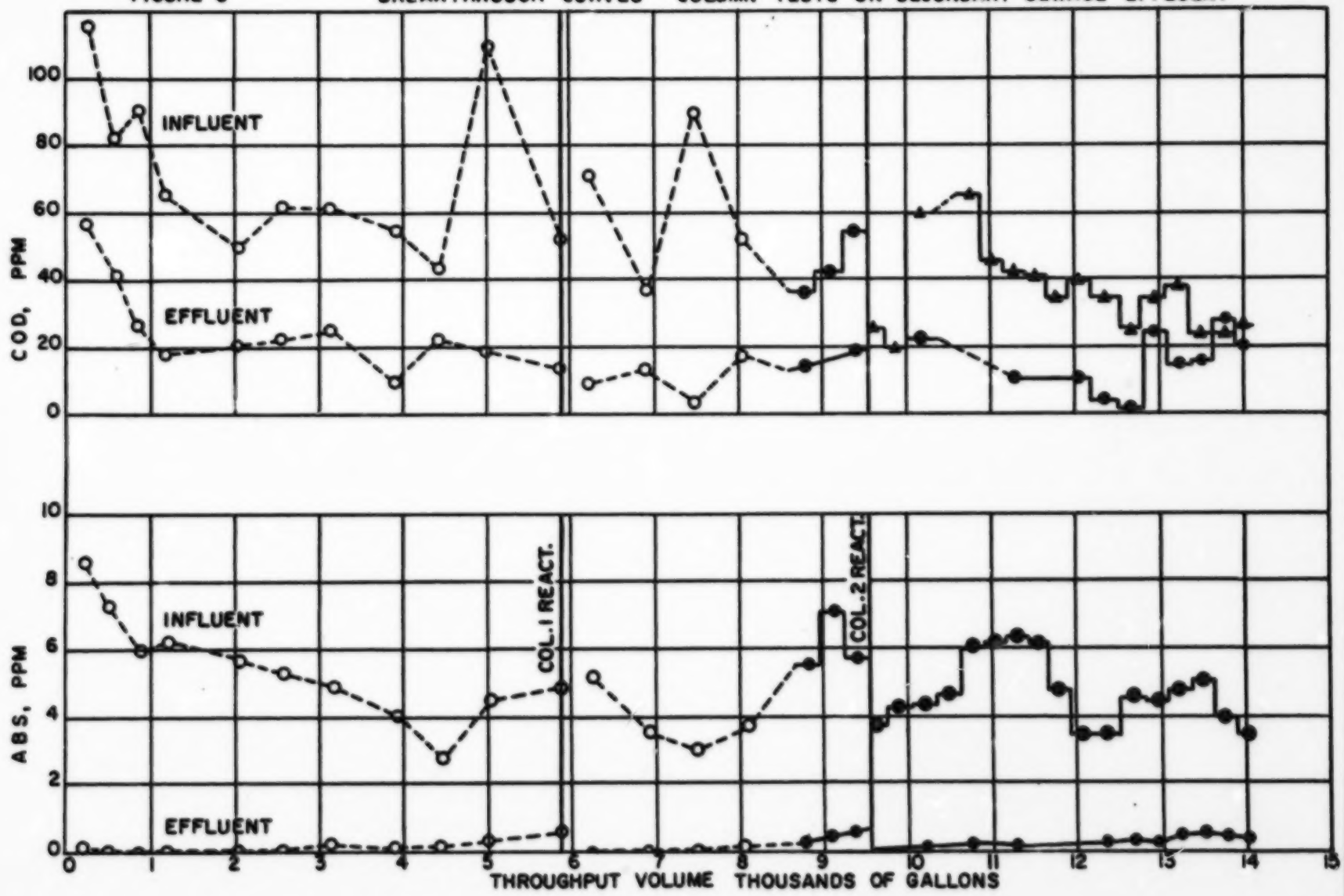


TABLE IV

SUMMARY OF DATA, COLUMN TESTS ON
SECONDARY SEWAGE EFFLUENT
AT 10 gpm./ft.^{2}

	COLUMN DATA					SEWAGE PLANT DATA				
CYCLE No.	THROUGHPUT Gal.	AV. COD CONTENT ppm. Influent	AV. COD CONTENT ppm. Effluent	AV. ABS CONTENT ppm. Influent	AV. ABS CONTENT ppm. Effluent	CARBON DOSAGE lb/1000 gal.	AV. FLOW mgd.	AV. BOD ppm. Raw	AV. BOD ppm. Final	AV. SUSPENDED SOLIDS ppm. Raw	AV. SUSPENDED SOLIDS ppm. Final
1	5,880	70	20	5.5	0.2	0.50	2.44	154	7	175	21
2	3,627	55	12	4.8	0.3	0.82	3.03	103	5	126	20
3	4,583	35	14	4.6	0.2	0.66	3.24	141	7	135	19

COLUMN TESTS ON SECONDARY SEWAGE EFFLUENT (continued)

It should be noted that in order to expedite the program a flow rate of 10 gpm./ft.^{2} was selected which is an unusually high flow rate for granular carbon columns. It is possible that increasing the contact time by using deeper beds or lower flow rates would effect better COD removal. The possibility that part of the residual COD may be due to a colloidal dispersion of carbon fines, to the sloughing off of algae or bacterial growths, or to an inorganic contaminant has not been precluded. Obviously this is an area in which more experimental work is necessary.

It is also obvious that the average influent COD during the third cycle (35 ppm.) was markedly lower than during the first and second cycles (70 and 55 ppm. respectively). The reason for this variation is not immediately apparent. The average total flow through the sewage treatment plant was higher during the third cycle. Since this increased flow is attributed to the infiltration of water from storm sewers in the older part of the sewer system, a dilution effect would be expected. However the dilution cannot account for all of the COD reduction. It is possible that the average COD values for the first and second cycles are unrealistically high since they are based on spot samples, and during the third cycle 24 hr. composite samples were collected. However the spot samples were collected at 7 a.m. and one would not expect peak values at this time. The ABS content of the secondary effluent appears to be more uniform than the COD content.

Carbon dosages calculated from these data yield values of 0.50, 0.82 and 0.66 pounds of carbon regenerated per thousand gallons of sewage effluent treated. These figures are quite preliminary. In order to determine an exact figure it would be necessary to continue the cyclic tests until equilibrium was established. This would involve a prohibitive period of time for a preliminary investigation. It appears however that the dosage can be conservatively estimated at less than 1 lb. C./1000 gal. for this particular sewage effluent.

On two occasions during the last cycle 5 day BOD values were obtained on grab samples of the influent and effluent of the column system. In one case the BOD was reduced from 16 ppm. to 6 ppm. by the carbon and in the other from 4.7 to 2.8 ppm.

ECONOMIC EVALUATION

Estimation of Activated Carbon Requirements:-

It was shown above that for a secondary sewage effluent containing approximately 50 ppm. COD and 5 ppm. ABS, the ABS can readily be reduced to less than 0.5 ppm. and the COD to the 12-20 ppm. range in a column process. If it is assumed that increasing the residence time will effect increased COD removal, the data can be extrapolated to obtain an approximation of the contact time necessary for COD removal to a residual concentration of 5 ppm. This extrapolation was made, assuming that the fraction of the COD remaining in the effluent would decrease exponentially with increasing bed depth, and a bed depth of 50 ft. at 10 gpm./ft.^{2}, corresponding to a residence of 5 min., ft.^{3}/gal. was obtained.

Estimation of Activated Carbon Requirements:- (continued)

The actual extent of saturation of the carbon with the organics that contribute to the COD is not known. For the purpose of arriving at an approximation of this figure it was assumed that the same general pattern would be followed by COD as that found for ABS in the column tests on ABS solutions. For the ABS data (Table II), a plot of percent saturation of the carbon vs. bed depth for residence times of 2 and 3 min., ft.^{3}/gal. showed maxima of 70 and 80% saturation respectively. It was estimated that a residence time of 5 min., ft.^{3}/gal. would increase the maximum to approximately 90% saturation.

In the sewage plant tests the cumulative carbon dosage after the third cycle was 0.66 lb./1000 gal. It was noted above that this figure would no doubt increase after cyclic equilibrium was established. A figure of 1 lb./1000 gal. is considered conservative. COD removal in the column tests at a residence time of 2 min.,ft.^{3}/gal. ranged from 60 to 80% and an estimated carbon saturation of 70% was effected. Assuming 100% COD removal at 5 min., ft.^{3}/gal. and 90% saturation of the carbon, the dosage at the higher residence time becomes, approximately, $1 \times 70/90 \times 100/60 = 1.3$ lb./1000 gal.

It was also noted above that considerable doubt existed that the capacity of the carbon would decrease in practice as drastically as it did in the accelerated reactivation tests. For the sake of conservatism however it is assumed that the average capacity will be 50% of virgin capacity. The average dosage then becomes 2.6 lb./1000 gal. For a 10 mgd. installation this amounts to 26,000 lb./day.

In relatively large installations for the thermal reactivation of granular carbon, overall reactivation losses range from 3 to 5% of the amount reactivated. This corresponds to activated carbon makeup requirements of between 780 and 1300 lb./day at a cost of from $235 to $390.

The initial charge of granular carbon required for the treatment of 10 mgd. at a residence time of 5 min., ft.^{3}/gal. amounts to 1,000,000 lb. for treatment and an additional 200,000 lb. in process for a total of 1,200,000 lb. and a cost of $360,000.

Cost of Plant Facilities:-

It should be emphasized that insufficient data is available at the present time to design a full scale installation for the treatment of secondary sewage effluent. The nature of the effluent and particularly the magnitude of the volumes involved are such that new concepts in adsorber design may have to be considered.

Based on existing knowledge, a flow sheet for a facility for the continuous activated carbon treatment of 10 mgd. of secondary sewage effluent was prepared. A simplified flow sheet is shown in Figure 7. Arbitrarily, fixed bed adsorbers piped for down flow operation were selected. In spite of the fact that this represents one of the simplest of the possible designs, it is estimated that the use of more complex adsorbers would not change the overall treatment cost significantly.

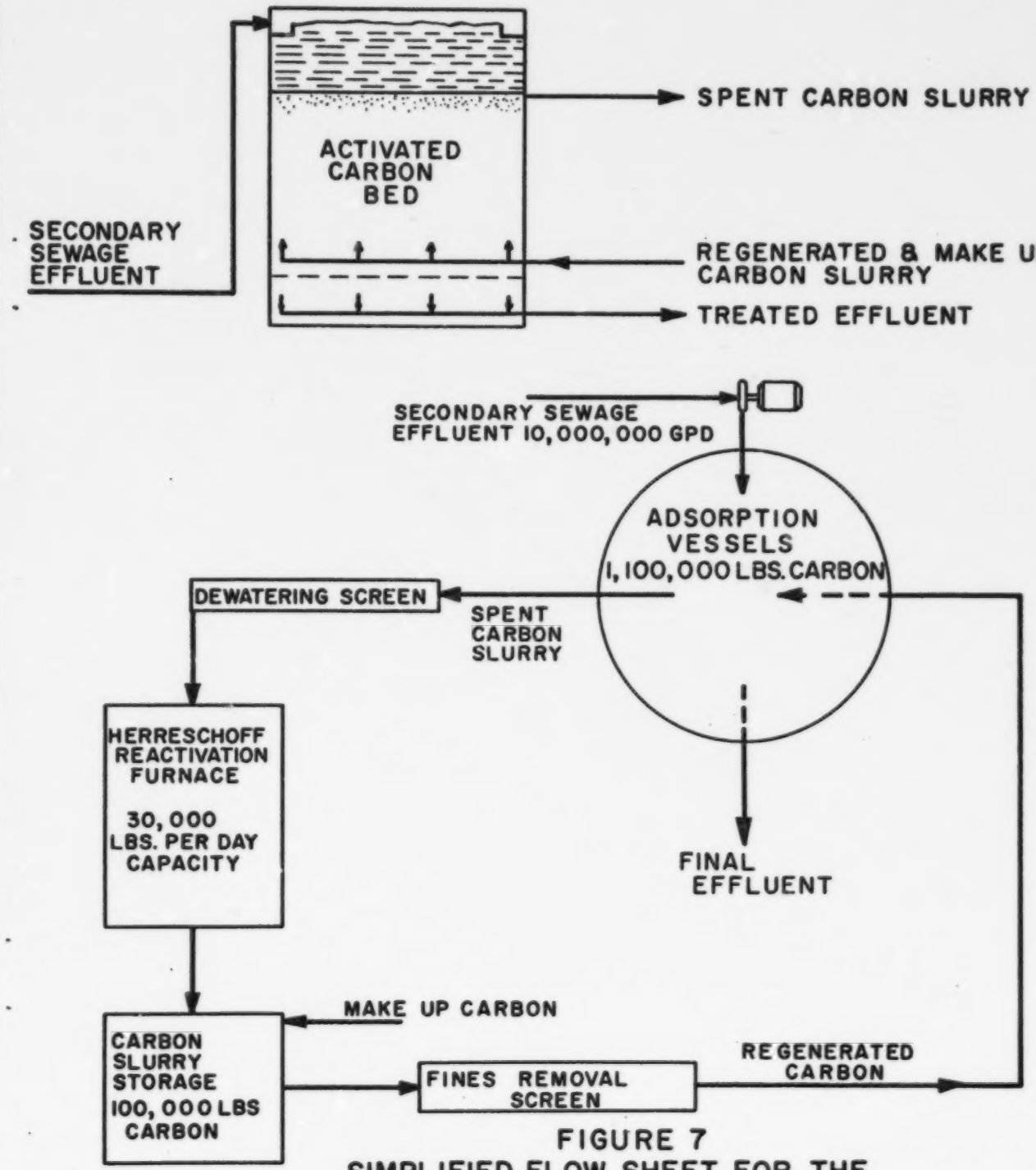


FIGURE 7
SIMPLIFIED FLOW SHEET FOR THE REMOVAL OF ABS & COD FROM SECONDARY SEWAGE EFFLUENT 10 mgpd.

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Cost of Plant Facilities:- (continued)

Reactivation equipment consisted of a Herreshoff furnace, spent and reactivated carbon storage tanks and all of the auxiliary equipment necessary for a complete hydraulic handling system for the transfer of the spent carbon from the adsorbers to the furnace and the reactivated carbon from the furnace to the adsorbers.

The process flow sheet was prepared in sufficient detail to show all of the major materials handling equipment. This equipment was selected to assure a workable although not necessarily the most efficient system. Instrumentation and control systems were selected to provide semiautomatic operation. The equipment was cost estimated to about the 30% certainty level and to the sub-total of the individual items, the estimated costs of site development, engineering and a reserve for contingency were added. The overall totals amounted to $450,000 for a 10 mgd. plant and $3,375,000 for a 100 mgd. plant.

Overall Treatment Costs:-

The overall treatment costs can be calculated from the above figures and from appropriate estimates of the cost of labor and utilities. Daily costs for a 10 mgd. and a 100 mgd. installation are summarized in Table V. Per diem capital costs are based on a 20 year life and a 5% interest rate. It is estimated that operating and maintenance labor would average 4 man hours per shift for a 10 mgd. throughput and 8 man hours per shift for a 100 mgd. throughput.

REACTIVATION TESTS

Batch Cyclic Reactivation Tests:-

Comparison of the ash analyses of spent carbon from the column tests on aqueous ABS solution with those of the virgin carbon revealed that a small increase in the sodium content and a marked increase in the calcium content of the carbon occurred. It was reasoned that the sodium ions associated with the sulfonic acid groups of the ABS were exchanged for calcium ions in the water after adsorption. Since calcium ions were believed more likely to contribute to insoluble ash than sodium ions, it was considered desirable to carry out the accelerated tests using a carbon exhausted with Ca-ABS.

Preliminary tests indicated that batch treatment of the granular carbon with a 1700 ppm. solution of Na-ABS, followed by an aqueous rinse, effected a 17% increase in the oven dry weight of the carbon. Assuming a molecular weight of 350 for the ABS salt this corresponds to approx. 0.5 meq. of ABS/g. of carbon. Subsequent batch treatment of the carbon with a 3400 ppm. $CaCl_2$ solution effected an increase in the calcium content amounting to 0.4 meq. Ca/g. From these observations it was concluded that the batch procedure would provide an accelerated method for loading the carbon with Ca-ABS.

TABLE V

ESTIMATED COSTS FOR THE TREATMENT OF
SECONDARY SEWAGE EFFLUENT

(Assuming a 20 year life and 5% interest)

	Cost $/day	
	10 mgd.	100 mgd.
Capital Investment		
Plant Facilities	120	1000
Initial Carbon Charge	100	1000
Operating Labor and Maintenance	80	160
Utilities	125	1000
Carbon Makeup	235-390	2350-3900
Total	660-815	5510-7060
Treatment Cost, $/1000 gal.	0.066-0.082	0.055-0.071

Batch Cyclic Reactivation Tests:- (continued)

Table VI summarizes the results obtained in each cycle and the properties of the virgin carbon and the carbon after the 10th reactivation are listed in Table VII.

From the data in Table VII it is immediately apparent that after ten cycles the ash content of the carbon has doubled and that there is a marked increase in the sodium and particularly the calcium contents. There is only a slight change in the molasses number which correlates with the surface area contributed by pores greater than approximately 28 Å in diameter. On the other hand there is a marked decrease in the iodine number which correlates with the total surface area. From these observations we would conclude that the fine pore structure of the carbon is blocked.

The high value (9.55%) of the acid soluble ash of the carbon after ten reactivations shown in Table VII is surprising. Repeat analyses gave essentially the same result. This observation suggests that acid washing the carbon after thermal reactivation would eliminate the build-up of water insoluble ash, and might increase the adsorptive capacity of the reactivated carbon. This phenomenon was not examined further in the current study but will be investigated briefly early in the second phase of the program. In an isotherm test the carbon after ten reactivations exhibited a total theoretical capacity of 8%-wt. ABS for the adsorption of ABS from a 9 ppm. solution compared to 20%-wt. for virgin carbon.

These results must be interpreted with considerable caution. In the first place, an accelerated test of this kind has not been conducted before and there is no way of knowing how it compares with field performance. Secondly the average amount of ABS adsorbed per cycle was 13.5%-wt. of the carbon. In the sewage plant tests the spent carbon that was regenerated had adsorbed approximately 4%-wt. ABS. Accordingly, one would not expect in practice the rapid inorganic build up encountered in the cyclic test. Further, it is anticipated that in practice 5% virgin carbon would be added each cycle for makeup. This would undoubtedly help maintain the quality of the adsorbent. In short, it is believed that cyclic regeneration tests in which the carbon is exhausted by contact with a real sewage effluent must be conducted before the effects of ash build-up can be realistically evaluated.

Reactivation of Spent Carbon from Sewage Plant Tests:-

The properties of the spent and reactivated carbons from these tests are summarized in Table VIII. In the sewage plant tests the spent carbon had adsorbed approximately 4%-wt. ABS, a value estimated from the breakthrough curves in Figure 6, plus, of course, an undetermined quantity of the organics that contribute to the COD. No difficulty was experienced in restoring this spent carbon to somewhat better than virgin activity. However, a marked increase in ash content can again be observed. This increased ash is in itself not alarming since the same phenomenon occurs in many other granular carbon applications, however, its ultimate effect on the adsorptive capacity of the carbon cannot be estimated from a single reactivation.

TABLE VI

SUMMARY OF BATCH REACTIVATION TESTS

Cycle No.	Apparent Density g./cc. Spent	Apparent Density g./cc. React.	ABS adsorbed (1) %-wt.	Activity Molasses No.	Activity Iodine No.
1	0.565	0.478	16.9	-	-
2	0.530	0.481	10.5	188	905
3	0.570	0.482	16.6	-	-
4	0.542	0.481	12.0	-	-
5	0.548	0.478	13.9	183	704
6	0.537	0.465	13.0	-	-
7	0.520	0.460	12.9	214	682
8	0.516	0.442	12.4	-	-
9	0.503	0.434	13.8	205	653
10	0.489	0.435	12.9	188	588

(1) Calculated from density difference

TABLE VII

PROPERTIES OF ACTIVATED CARBON BEFORE AND AFTER BATCH REACTIVATION TESTS

	VIRGIN CARBON	AFTER 10 REACTIVATIONS
Apparent Density, g./cc.	0.480	0.435
Total Ash, %-wt.	5.30	11.90
Water Soluble Ash, %-wt.	0.03	0.02
Acid Soluble Ash, %-wt.	0.94	9.55
Ca, %-wt.	0.08	2.05
Mg, %-wt.	0.05	0.03
Na, %-wt.	0.07	0.84
Molasses No.	195	188
Iodine No.	942	588

TABLE VIII

PROPERTIES OF SPENT AND REACTIVATED CARBON
FROM SEWAGE PLANT TESTS

	SPENT		REACTIVATED		VIRGIN
	Col.1	Col.2	Col.1	Col.2	
Apparent Density, g./cc.	0.525	0.528	0.484	0.483	0.480
Ash, %-wt.	6.07	5.84	6.70	6.82	5.36
Molasses number	182	203	200	196	195
Iodine number	830	824	1085	1081	942

Reactivation Tests with Steam at Lower Temperatures:-

These tests were initiated to briefly examine the feasibility of regenerating the spent carbon in the adsorbers by acid treatment followed by steam regeneration. It was reasoned that conversion of the salt form of the adsorbed ABS to the free acid form might make the adsorbate sufficiently unstable to permit a low temperature regeneration.

Preliminary tests indicated that steaming alone was insufficient and that it was necessary to resort to steaming plus external heating to effect a reasonable degree of activation. The results of tests in which acid treated carbon was steamed at temperatures of 650°F. and 950°F. are given in Table IX. At 650°F. a prohibitively long time (288 min.) was required to achieve a satisfactory degree of activation. The time was reduced to 70 minutes by increasing the temperature to 950°F. although in this case the degree of reactivation was not satisfactory. For the same carbon conventional thermal reactivation required from 15 - 20 min. in the laboratory weighing furnace.

This line of investigation was not pursued further since it is believed that an acid proof adsorber equipped with an external heater to maintain the carbon at a temperature of from 650 - 950°F. would be economically inpractical.

Conversion of Adsorbed ABS to Free Acid or Sodium Salt:-

Analysis of the spent carbon from the first column section used for the treatment of aqueous ABS solution at 2.5 gpm./ft.^{2}, after rinsing and drying, showed that it contained 0.85%-wt. Ca., 0.05%-wt. Mg. and 0.11%-wt. Na. Corresponding values for the virgin carbon are 0.08% Ca., 0.05% Mg. and 0.07% Na. The spent carbon had adsorbed approximately 24% of its original weight of ABS. Assuming a molecular weight of 350 for the sodium ABS salt this corresponds to 0.68 meq./g. of carbon. The high calcium content of the spent material (0.43 meq./g.) and the comparatively low sodium content (0.05 meq./g.) can only be explained by assuming that most of the adsorbed ABS is in the form of the calcium salt.

The results obtained by percolating one liter of 5% HCl through 60 g. of the spent carbon are shown graphically in Figure 8. Analysis of the effluent fractions indicated that approximately 60% of the total calcium and all of the magnesium was eluted after one liter of effluent was collected. The fact that this is an ion exchange mechanism and not dissolution of calcium and magnesium salts was demonstrated by two experiments.

First, treatment of a second 60 g. sample of the spent carbon with one liter of 5% sodium chloride gave elution curves (Figure 8) similar to those obtained for 5% hydrochloric acid. Analysis of the effluent fractions indicated that approximately 55% of the calcium and 50% of the magnesium was eluted from the carbon.

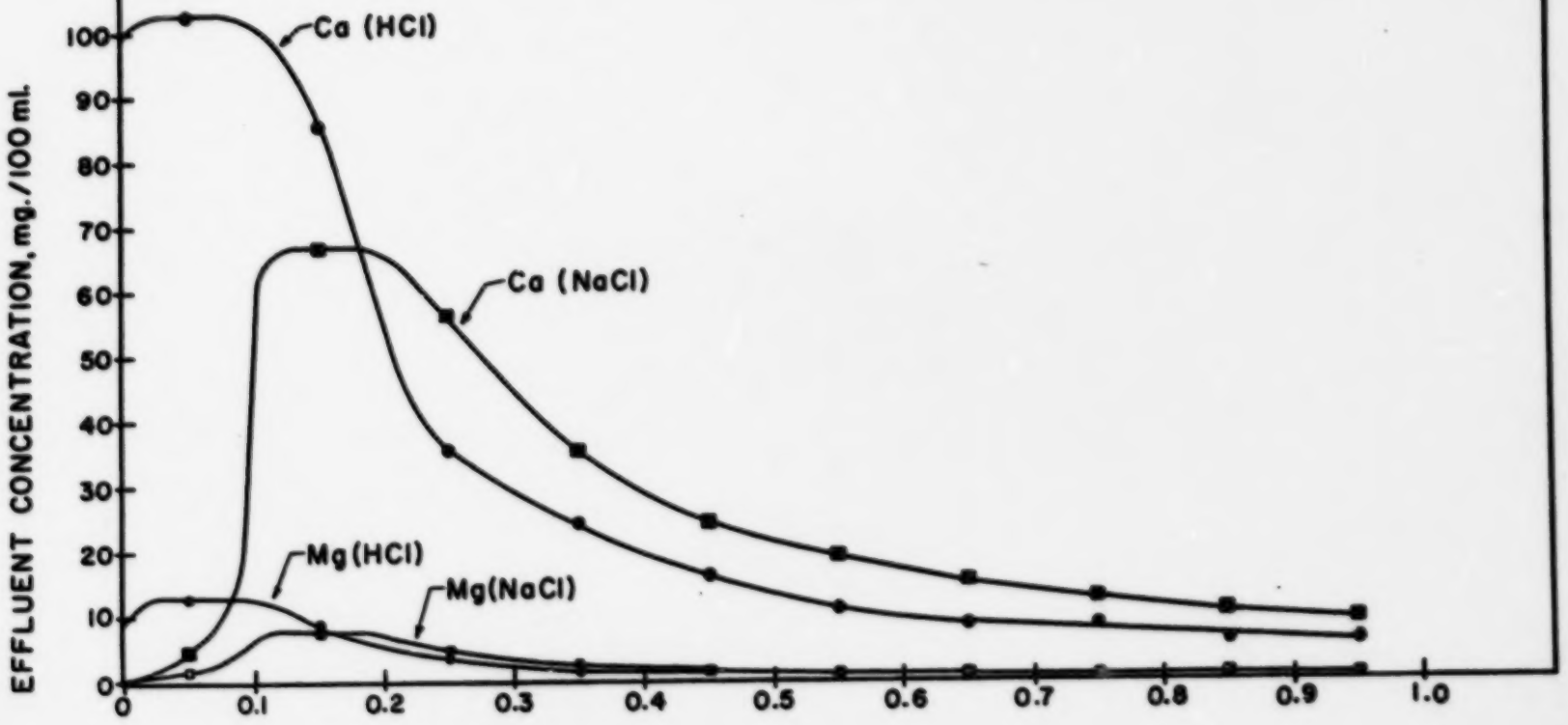
TABLE IX

PROPERTIES OF ABS SATURATED CARBON BEFORE
AND AFTER ACID TREATMENT AND LOW TEMPERATURE STEAM REACTIVATION

	SPENT	REACTIVATED		VIRGIN
Furnace Temp. °F.	-	950	650	-
Time required, min.	-	70	288	-
Apperent Density, g./cc.	0.594	0.503	0.490	0.480
Molasses No.	< 166	173	208	195
Iodine No.	519	845	869	942

FIGURE 8

ELUTION OF Ca & Mg FROM Ca & Mg ABS SATURATED CARBON USING 5% HCl AND 5% NaCl.



Conversion of Adsorbed ABS to Free Acid or Sodium Salt:- (continued)

Secondly, after the hydrochloric acid treatment one liter of tap water containing 13 ppm. Ca. and 4 ppm. Mg. was percolated through the carbon bed. After the acid was displaced 800 ml. of effluent containing 2.2 ppm. of Ca. and 0.7 ppm. Mg. was collected, indicating that the mechanism is reversible ion exchange.

These experiments were performed in order to determine the ease with which the adsorbed Ca. or Mg. ABS could be converted to the free acid or Na. salt. It was reasoned that if this conversion could be accomplished prior to thermal reactivation, a water soluble inorganic residue might be formed, and the build-up of insoluble ash minimized. Work in this direction was discontinued because of the difficulty in converting more than approximately half of the adsorbed ABS to the free acid or sodium salt.

CORROSION TEST

Examination of the mild steel corrosion test strip after it had been in contact with activated carbon and secondary sewage effluent for a 31 day period revealed that it was severely pitted. The weight before the test was 14.210 g. and after the test 12.229 g. amounting to a weight loss of 13.9%. This corresponds to a loss of 1.365 mg./cm.$_2$ day.

Although additional tests will be necessary before mild steel adsorbers are ruled out, this suggests that consideration be given to the use of internally coated adsorbers.

APPENDIX

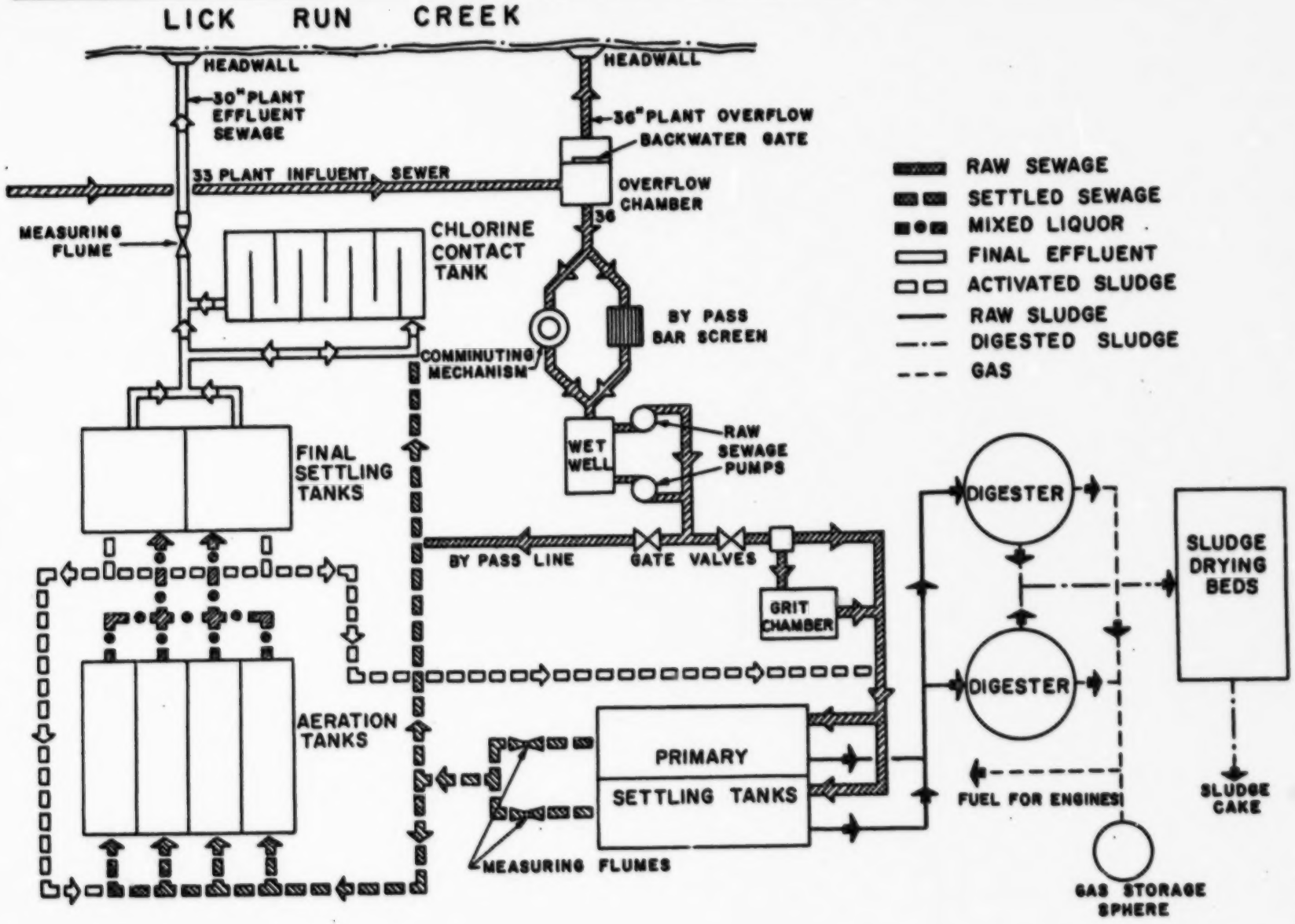
PLEASANT HILLS SEWAGE TREATMENT PLANT

A flow diagram of the plant is shown in Figure 2. Raw sewage flows through a comminuting screen to a wet well and from there is pumped to a grit chamber where the retention time is 6 minutes at the design average flow rate of 3.0 mgd. From there the sewage flows to the primary settling tanks. The retention time here is 1.8 hours. Sludge is withdrawn to hoppers at the influent end by means of a longitudinal and cross collecting scraping mechanism. Scum and floating particles are removed by revolving scum troughs near the outlet end.

Settled sewage flows from the primary tanks through a series of V notched weirs into a sludge mixing channel. Here return sludge from the final tanks, normally 25% by volume is admixed before the sewage goes to the aeration tanks. A by-pass line is provided so that settled sewage from the primary tanks can be diverted to the chlorination tanks under emergency conditions. In the aeration tanks the retention time is 6 hours. Mixed liquor from the aeration tanks flows through a concrete measuring and flow balancing system into the center feed wells of the final tanks where it is retained for two hours. Final effluent flows over weirs into collecting troughs extending around the periphery of the tanks and from there to a baffled chlorination tank where the retention time is approximately 18 minutes. Sludge is withdrawn from the secondary tanks by means of a rotating collector to a sludge well. From there it is pumped to a sludge division box from which it flows by gravity to the mixing channel and to the primary tank influent channel.

FIGURE 9

FLOW DIAGRAM, PLEASANT HILLS SEWAGE TREATMENT PLANT



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